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Overview of Unbound Base Specifications and Effects of Stiffness, Uniformity and Density on Base Layer Pavement Performance

Prepared for
WHRP Flexible Pavement Technical Oversight Committee

Prepared by
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WisDOT Research & Library Unit

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Keywords: HMA, unbound base, specifications, measurement tools, stiffness, uniformity, pavement performance, testing, acceptance test.

Summary

We found 17 citations for documents published in 2006 or later. Four of the citations were published in 2009, four in 2008, five in 2007, and four in 2006. Three of the 17 citations refer to NCHRP reports. Three of these reports refer to state DOT studies.

Citations

Links to online copies of cited literature are provided when available. Contact the WisDOT Library to obtain hard copies of citations.

Title: Nonlinear Pavement Foundation Modeling for Three-Dimensional Finite-Element Analysis of Flexible Pavements
Author(s): Kim, Minkwan; Tutumluer, Erol; Kwon, Jayhyun
Date: September/October 2009
Source/URL: *International Journal of Geomechanics*, Vol. 9, No. 5, pages 195-208.
Description: 14 pages
Contents: Pavement foundation geomaterials, i.e., fine-grained subgrade soils and unbound aggregates used in untreated base/subbase layers, exhibit nonlinear behavior under repeated wheel loads. This nonlinear behavior is commonly characterized by stress-dependent resilient modulus material models that need to be incorporated into finite element (FE) based mechanistic pavement analysis methods to predict more accurately the pavement resilient responses, such as stress, strain, and deformation. Many general-purpose FE programs have been used to predict such pavement responses under various traffic loading conditions while not considering properly material characterizations of the unbound aggregate base/subbase and subgrade soil layers. This paper describes the recent pavement FE modeling research efforts at the University of Illinois focused on using both the specific-purpose

axisymmetric and general-purpose three-dimensional (3D) FE programs for flexible pavement analyses. To properly characterize the resilient behavior of pavement foundations, nonlinear stress-dependent modulus models have been programmed in a user material subroutine (UMAT) in the commercial general-purpose finite-element program ABAQUS. The results indicated that proper characterizations of the nonlinear stress-dependent geomaterials significantly impacted accurate predictions of critical pavement responses. The prediction ability of the developed nonlinear UMAT characterization was next validated by predicting similar pavement critical responses to those measured from field instrumented pavement test sections. Different resilient modulus models, considering both axisymmetric and 3D stress states, developed from true triaxial test data on unbound granular materials were also studied. When the intermediate principal stresses were taken into account in the 3D modulus model development unlike in the axisymmetric models, somewhat lower asphalt concrete tensile strains were obtained from 3D nonlinear FE analyses of flexible pavements with unbound aggregate bases.

Title: Comparison of Cyclic Triaxial Behavior of Unbound Granular Material Under Constant and Variable Confining Pressure
Author(s): Rondón, H. A.; Wichtmann, T.; Triantafyllidis, T.; Lizcano, A.
Date: July 2009
Source/URL: *Journal of Transportation Engineering*, Vol. 135, No. 7, pages 467-478.
Description: 12 pages
Contents: Cyclic stresses due to passing wheels impose an accumulation of permanent strains in layers of unbound granular materials (UGMs) of flexible pavements. The hollow cylinder triaxial test would be the most appropriate test to simulate the in situ stress conditions but it is difficult to perform on UGMs due to their large maximum grain size. The simpler axisymmetric cyclic triaxial test does not consider the shear stress components. It can be performed with a constant confining pressure (CCP) or a variable confining pressure (VCP). CCP and VCP tests are commonly assumed to deliver similar residual and resilient strains as long as the average stress is the same. Thus, the simpler CCP test is mostly used in pavement engineering. However, this assumption is based on limited test data in the literature and may not be on the safe side. The present paper documents a comparative study of CCP and VCP tests on UGM. The study is mainly dedicated to the permanent deformations. The results show that only for some special stress paths do both types of tests deliver similar permanent axial or volumetric strains. For some other stress paths the CCP tests may underestimate the permanent axial strain in comparison to the corresponding VCP test.

Title: Analysis of Using Reclaimed Asphalt Pavement (RAP) as a Base Course Material
Author(s): Locander, Robert
Date: May 2009
Source/URL: Report from Colorado Department of Transportation
Description: 68 pages
Contents: The Colorado Department of Transportation (CDOT) has used Reclaimed Asphalt Pavement (RAP) as a base on many projects as a reconstruction strategy. CDOT's specifications allow RAP to be substituted for unbound aggregate base course (ABC). The laboratory tested properties of reclaimed asphalt pavement are similar to CDOT's aggregate base course specifications. Conclusions are: RAP has pavement design properties similar to aggregate base course; a suggested gradation specification band is presented for RAP; RAP requirements for PI and LL may be the same as ABC Class 6, PI not to exceed six and LL not greater than 30; the stiffness strength properties obtained from laboratory testing shows that RAP has stiffness strength above an unbound ABC Class 6; and the permeability of RAP showed a slight increase over an unbound ABC Class 6.

Title: Evaluation of the Compaction Characteristics of Unbound Material Using the Superpave Gyratory Compactor
Author(s): Lambert, Nicholas; Denny, Kyle; Sukumaran, Beena; Mehta, Yusuf
Date: 2009
Source/URL: Conference Proceeding Paper from Asphalt Material Characterization, Accelerated Testing, and Highway Management: Selected Papers from the 2009 GeoHunan International Conference (GSP 190), pages 65-71.
Description: 7 pages
Contents: During previous full-scale tests at the National Airport Pavement Facility (NAPTF) at Atlantic City, USA, significant consolidation of the subbase layer occurred during aircraft trafficking accompanied by shear flow failure in the underlying low strength subgrade material. In order to understand the compaction and shear flow characteristics of the subbase layer during construction and trafficking, the material was compacted in the Superpave Gyratory Compactor (SGC) at various stress levels and at different moisture contents. Since the SGC is primarily used for compaction of asphalt concrete, the compaction characteristics in the Superpave Gyratory Test were calibrated to field compaction of the subbase material during construction at similar moisture contents. The field data collected included the change in density of the subbase layer during compaction with number of passes of the

roller. The calibration was done by comparing the shape of the curve. The calibration provided the benchmark values for laboratory evaluation of unbound material in SGC, such as stress level and the gyratory angle of testing. The shape of the compaction curve and the density at various gyrations levels provided an insight into the understanding of the compaction characteristics of the subbase material under roller compaction. This paper provides the airport pavement designers the efficacy of using the SGC as a means of evaluating the performance of unbound material during compaction.

Title: Development of Performance Related Specifications for Asphalt Pavements in the State of Arizona
Author(s): Witczak, Matthew W.
Date: May 2008
Source/URL: Report from Arizona Department of Transportation, http://www.dot.state.az.us/TPD/ATRC/publications/project_reports/PDF/AZ402-2.pdf.
Description: 74 pages
Contents: This report presents an Executive Summary of a comprehensive study conducted by Arizona State University regarding a series of 11 separate projects relating to the implementation of the Mechanistic-Empirical Pavement Design Guide (MEPDG) for the state of Arizona. The individual study project reports deal with the characterization of a variety of AC binder types used by the Arizona Department of Transportation (ADOT) (Project 2); characterization results of E* Master Curve results for typical AC mixtures used in Arizona (Project 3); the characterization of these typical AC mixtures for Thermal Fracture (Project 4), Permanent Deformation (Project 5), and Load associated Fatigue (Project 6). In addition, recommendations are made in Project 7 regarding the implementation of the Simple Performance Test for AC Mixtures. Projects 8 and 9 focus on unbound bases/subbases and subgrades. Project 8 describes the results of nonlinear modulus of resilience response for a variety of typical unbound bases and subgrades. Project 9 deals with the development of an unbound material permanent deformation database and development of a more universal permanent strain model. In the Project 10 study report, the state of Arizona has been subdivided on the basis of relatively unique climatic regions based upon regional geomorphology. Finally, Project 11 is a very comprehensive report study of the existing ADOT traffic files for eventual inclusion with the MEPDG. A computerized (spreadsheet) traffic database of the entire ADOT highway network was conducted. This database incorporates every mile of the Arizona highway network (6 interstates, 13 U.S. highways and 86 state highways). Four significant traffic factors are included in the database: Average Annual Daily Traffic (AADT), Annual Growth Rate, Percent Trucks, and Vehicle Classification Percentage (VCP). Relatively homogeneous traffic units were selected based on existing ADOT HPMS and VCP stations.

Title: Performance-Related Tests of Recycled Aggregates for Use in Unbound Pavement Layers
Principal Investigator(s): Saeed, Athar
Date: 2008
Source/URL: NCHRP Report 598, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_598.pdf.
Description: 64 pages
Contents: This report contains recommendations for performance-related procedures to test and select recycled hot-mix asphalt (HMA) and portland cement concrete (PCC) materials for use in unbound layers of highway pavements. The report provides a comprehensive description of research intended to help materials engineers evaluate and select the reclaimed asphalt pavement (RAP) and reclaimed concrete pavement (RCP) materials that should contribute to good performing pavements. Also, the report describes procedures for the recommended tests. The contents of this report will be of immediate interest to materials engineers, researchers, and others concerned with the construction and performance of asphalt and PCC pavements.

Title: Performance Tests for Road Aggregates and Alternative Materials
Author(s): Arnold, Greg; Werkmeister, Sabine; Alabaster, David
Date: 2008
Source/URL: Report from Land Transport New Zealand,
http://www.landtransport.govt.nz/research/reports/335.pdf.
Description: 64 pages
Contents: At least half the roughness and wheeltrack rutting that occur on surface courses in New Zealand are contributed to by aggregates used as base materials in thin surface granular pavements. At this point, there does not exist, in specifications, a reliable and cost-effective way to measure an aggregate's resistance to rutting. This study utilized several test methods of repeated load triaxial equipment to examine them for use in base course aggregate specifications. Traffic load limits were determined by pavement finite modeling and rut depth prediction methods. Results indicate that the average slope from the six stage repeated load triaxial test was the best predictor of traffic load limit. Therefore, this test was recommended for utilization in specifications for base courses.

Title: Estimating Stiffness of Subgrade and Unbound Materials for Pavement Design
Author(s): Puppala, Anand J.
Date: 2008
Source/URL: NCHRP Synthesis Report,
http://www.trb.org/Publications/Blurbs/Estimating_Stiffness_of_Subgrade_and_Unbound_Mater_160578.aspx.
Description: 139 pages
Contents: The new Mechanistic-Empirical Pavement Design Guide (MEPDG) and other existing pavement design guides use resilient modulus (MR) as the primary input parameter when characterizing stiffness of subsoils and unbound bases. Resilient modulus of soils is typically determined either by using laboratory tests or field tests. This report was prepared to describe the significance of the resilient modulus property, various methods of determining this property of subsoils and unbound bases, and the application of this parameter in the mechanistic-empirical pavement design guide. The report will be of interest to design, geotechnical and materials engineers and technicians.

Title: The Effect of Grading on the Performance of Basecourse Aggregate
Author(s): Arnold, Greg; Werkmeister, Sabine; Alabaster, David
Date: August 2007
Source/URL: Report from the Land Transport New Zealand.
Description: 54 pages
Contents: A laboratory study was undertaken to determine the effect of grading/particle size distribution on permanent deformation in multi-stage repeated load triaxial (RLT) tests. Results showed the coarse gradings with a Talbot's exponent *n*-value of 0.8 had the least amount of permanent deformation for high-moisture contents near saturation. Finer gradings with an *n*-value of 0.3 had the least deformation in all of the tests in dry conditions at less than 70% of optimum moisture content. Similar performance in terms of permanent deformation was obtained if variations of the *n*-value were less than 13%. Based on limiting the variations in *n*-value to $\pm$13% new grading envelopes for use in the new Transit New Zealand specification for RLT testing were proposed.

Title: Test Methods for Characterizing Aggregate Shape, Texture, and Angularity
Principal Investigator(s): Masad, Eyad; Al-Rousan, Taleb; Button, Joe W.; Little, Dallas N.; Tutumluer, Erol
Date: July 2007
Source/URL: NCHRP Report 555, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_555.pdf.
Description: 93 pages
Contents: This report presents a methodology for classifying aggregates based on the distribution of shape, texture, and angularity characteristics and recommends a test method for measuring these characteristics to help improve specifications for aggregates used in highway pavements. The test method measures shape, texture, and angularity characteristics of aggregates used in hot-mix asphalt, hydraulic cement concrete, and unbound base and subbase layers of highway pavements, and it is appropriate for use in central and field laboratories. This report will be of particular interest to materials engineers, researchers, and others concerned with the design and construction of flexible and rigid pavements.

Title: Use of Dynamic Cone Penetrometer in Subgrade and Base Acceptance
Author(s): Wu, Shin; Sargand, Shad
Date: April 2007
Source/URL: Report from Ohio Department of Transportation, http://www.dot.state.oh.us/research/2007/Pavements/14817-FR.pdf.
Description: 120 pages
Contents: The Dynamic Cone Penetrometer (DCP) is a simple device for measuring the stiffness of unbound materials. The DCP works by driving a steel rod into bases and soil with a preset amount of energy; the stiffness of unbound materials at different depths can be measured by continuously monitoring the rate of penetration, yielding a stiffness profile. With its ability to collect and analyze date quickly and easily, the DCP compares favorably with other devices used to evaluate an in-situ base and subgrade during construction. The DCP is also the only device available today that can evaluate subgrade quality in all three dimensions. Most highway agencies accept unbound materials in base and subgrade based on density tests. But density is not a measurement of the strength (stiffness) of these materials. Field data collected in this study indicated that accepting the subgrade based on density tests did not guarantee the strength met design requirements. Accepting the base and subgrade based on density is thus one of the weak links in the process of designing and constructing pavement. During the 2003 and 2004 construction seasons, the Ohio Research Institute for Transportation and the Environment (ORITE) collected DCP data from 10 road projects in Ohio. Experience from this study proves that the DCP is a viable alternative device to evaluate in-situ base and subgrade materials during construction. Data collected shows that engineers can use the DCP to quantify the construction quality of the as-built materials. Based on this study, ORITE concludes that adopting DCP testing in unbound material acceptance specifications can greatly improve the monitoring of final product quality and thus enhance pavement performance. This report describes the ORITE study. The report also provides a construction site DCP testing procedure and proposes a set of DCP unbound material acceptance criteria and standards.

Title: Environmental Effects on the Predicted Service Life of Flexible Pavements
Author(s): Zuo, Gang; Drummr, Eric C.; Meier, Roger W.
Date: January 2007
Source/URL: *Journal of Transportation Engineering*, Vol. 133, No. 1, pages 47-56.
Description: 10 pages
Contents: Mechanistic-empirical pavement design methods for flexible pavements are based on the assumption that pavement life is inversely related to the magnitude of the traffic-induced pavement strains. These strains vary with the stiffness of various pavement layers. The stiffness of the asphalt varies with temperature and the stiffness of the unbound base and subgrade materials varies with water content. Because these relationships are nonlinear, the additional pavement life consumed by wheel loads at higher-than-average temperatures or water contents is not offset by savings at lower-than-average temperatures or water contents. Furthermore, the temperature and moisture effects cannot be considered separately and superimposed, they must be considered together. In this paper, seasonal temperature and water content variations observed at instrumented pavement sites in Tennessee are idealized and the combined effects of these seasonal changes on predicted pavement life are evaluated for three typical pavement profiles. The results of the parametric study show that the temperature averaging period, the temperature gradient in the asphalt, and the timing and duration of wet base and subgrade conditions all affect the estimation of pavement life.

Title: Forensic Investigations of Roadway Pavement Failures
Author(s): Chen, Dar-Hao; Scullion, Tom
Date: 2007
Source/URL: Conference Proceeding Paper from Transportation Research Board 86th Annual Meeting.
Description: 27 pages
Contents: Forensic investigations of pavement failures are critical, as the information gained can be used to identify the underlying cause of the problem, develop an optimal rehabilitation strategy, and to resolve construction disputes. The Texas Department of Transportation has had a formalized forensic team approach for over 10 years. Application of nondestructive testing such as the Ground Penetrating Radar (GPR) and Falling Weight Deflectometer (FWD), as well as field testing such as Dynamic Cone Penetration (DCP), coring, and laboratory testing have been found critical to these forensic investigations on flexible pavements. The root causes of the pavement failures often can be identified through these tools, in conjunction with thorough review of construction records and rehabilitation history. In this paper three field projects are presented to illustrate the integrated approach used widely in Texas. In each case the combined GPR and FWD data was extremely useful at identifying contributing factors; such as stripping in the hot mix or localized areas of wet or weak base. The DCP is used for validating problems with base and subbase layers. To determine the optimum rehabilitation strategy, it requires knowledge of what is the main cause of the problem. Laboratory tests are often required to complete the investigation especially if the repair

strategy calls for in place recycling of the existing structure. The extent of stripping and high porosity that caused delamination for projects 1 and 2 were detected by GPR and verified by core samples. This combination (GPR+coring) was used to map the entire project. GPR, FWD, DCP and field soil samples all showed indications that the existing base on project 1 was wet and the stiffness was only about 1/3 of a typical flexible base in Texas. FWD data demonstrates that the pavement structure for projects 1 and 2 were inadequate, so a rehabilitation strategy was selected that included structural strengthening. In project 3, GPR, lab density, and permeability tests indicate that the dramatic pavement failures were attributed to moisture entering the base through a poorly compacted AC layer and poor longitudinal joints. The base material was found to be highly susceptible to moisture. It did not meet TxDOT's compressive strength requirements when subjected to capillary soaking. The repetitive triaxial test results revealed that the stiffness and load carrying capability became inadequate when the base materials were exposed to moisture. The techniques demonstrated in this study are widely used within Texas and are applicable to a wide range of pavement forensic studies.

Title: Analysis of Flexible Pavement Response and Performance Using Isotropic and Anisotropic Material Properties
Author(s): Masad, Sanaa; Little, Dallas; Masad, Eyad
Date: April 2006
Source/URL: *Journal of Transportation Engineering*, Vol. 132, Issue 4, pages 342-349.
Description: 8 pages
Contents: Several research studies have shown that unbound pavement layers exhibit anisotropic properties. Anisotropy is caused by the preferred orientation of the aggregate, to which both the shape characteristics of the aggregate and the compaction force itself contribute. The result is that unbound pavement layers have higher stiffness in the vertical direction than in the horizontal direction. The efficacy of using anisotropic properties to represent unbound layers is demonstrated by comparing pavement surface deflection measurements under wheel loads to finite element predictions based on models that incorporate isotropic and anisotropic properties for the unbound base and subbase layers. The surface deflections in the flexible pavements of the AASHO road test were selected for this comparison because the AASHO road test is such a widely used database and because of the tight control of traffic, pavement cross sections, and material quality at the road test. The paper also analyzes the influence of characterizing pavement layers as isotropic and anisotropic on the predictions of fatigue and permanent deformation performance of flexible pavements using the recently developed National Cooperative Highway Research Program 1-37A models. The results show that the anisotropic behavior of pavement layers explains part of the shift and calibration factors used to relate laboratory measurements to field performance.

Title: Resilient Modulus and Permanent Deformation Test for Unbound Materials
Author(s): Abushoglin, F; Khogali, W.
Date: 2006
Source/URL: *Manual from the National Research Council of Canada,*
http://irc.nrc-cnrc.gc.ca/pubs/ir/ir872/ir872.pdf.
Description: 47 pages
Contents: This manual describes procedures for preparing and testing unbound materials, including cohesive and granular materials, for the determination of the resilient modulus (Mr) and permanent deformation response. Samples are to be tested under conditions prevailing in the road layer in which the evaluated material is located. These conditions include density and moisture state as well as the level of traffic-induced stress estimated for the layer under consideration.

Title: Effects of Groundwater Table Depths on Predicted Performance of Pavements
Author(s): Sadasivam, S.; Morian, Dennis Alan
Date: 2006
Source/URL: Conference Proceeding Paper from Transportation Research Board 85th Annual Meeting.
Description: 12 pages
Contents: The depth of ground water table (GWT) has a profound effect on the performance of pavements. A rise in GWT depth influences the moisture content of the unbound materials and subgrade soils, thereby reducing their strength. The reduced stiffness in unbound materials and subgrade layers contributes to various pavement distresses. GWT depth is a key input parameter in both the 2002 design guide and EICM software. A sensitivity analysis was conducted to study the effects of water table depth on pavement performance, as predicted by the new NCHRP 1-37 software. This paper evaluates the influence of water table depth on performance parameters for six different types of soils. The performance parameters considered in this analysis are top-down cracking, bottom-up cracking and rutting. In this study, two typical pavement structures were analyzed using the NCHRP 1-37 software for a 20 year design period. The results show that the GWT depth parameter affects the pavement performance predictions. As

water table increases, predicted top-down cracking at the surface decreases, whereas the fatigue cracking at the bottom of the asphalt concrete layer increases. The level of water table has no significant effect on the rutting accumulated on the asphalt concrete layer. The subgrade rutting is greatly influenced by the depth of ground water table and the predicted rutting exhibits different trends for silty and clayey soils. The predictions of subgrade rutting were compared with the Ayres model for permanent deformation of unbound materials. The analysis indicates that the proposed 2002 design guide software underpredicts the subgrade rutting for silty soils when the ground water table is less than 10 feet. These results also highlight the importance of appropriately characterizing the GWT parameter for highway agencies planning to use the 1-37 software.

Title: A Case Study on Quality Management of Unbound Layers with Seismic Methods
Author(s): Nazarian, Soheil; Celaya, Manuel
Date: 2006
Source/URL: Conference Proceeding Paper from GeoCongress 2006: Geotechnical Engineering in the Information Technology Age, pages 1-6.
Description: 7 pages
Contents: The structural design of highways is based on engineering parameters, such as strength or stiffness. Unfortunately, construction specifications are not based on these properties. Unfortunately, acceptance criteria are typically based on adequate thickness or density of the placed materials. A procedure to measure the modulus of each pavement layer after placement with seismic technology is presented. Field and laboratory tests are incorporated so their results can be reconciled without any scaling or simplifying assumptions. In this paper, the overall method and procedures to establish the accuracy and repeatability of the methods are described and a case studied is also included.